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NEPTUNE.

LIVERPOOL. Equatoreal. (Mr. Hartnup.)

1849.	Green. M.T. h m s	R.A. h m s	N.P.D. ° ′ ″	Computed.—Observed. R.A. s	Computed.—Observed. N.P.D. ″
Oct. 28	8 40 23	22 17 25·68	101 24 52·72	+0·09	—0·05
Nov. 3	7 53 6	15·95	25 42·38	0·10	+0·27
12	7 13 17	9·83	26 9·53	0·04	—0·10
13	8 25 50	9·64	26 7·53	0·19	+1·16
15	5 56 59	10·07	26 5·19	0·05	+0·10
16	7 28 50	10·31	26 1·73	+0·17	+0·43
24	5 56 18	17·97	25 12·93	—0·04	—0·54
26	5 28 14	21·05	24 53·51	+0·02	0·84
27	5 16 40	22·80	24 42·56	0·05	0·85
28	6 7 18	24·77	24 31·36	0·06	1·87
30	7 35 46	22 17 29·04	101 24 4·30	+0·16	—1·44

"The observations are corrected for refraction and parallax. The star of comparison for all the observations is *σ Aquarii*. The mean R.A. 22$^{\rm h}$ 22$^{\rm m}$ 39$^{\rm s}$·01, and N.P.D. 101° 26′ 56″·0, for Jan. 1, 1849, has been taken from the Greenwich catalogue of 1439 stars for 1840.

"The computed places were deduced from Mr. Sears C. Walker's ephemeris, published in the *Smithsonian Contributions to Knowledge*. Appendix I. to Vol. II."

The Astronomer Royal resigned the chair to the Rev. R. Sheepshanks, and gave an oral statement, illustrated by models and diagrams, "On the Method of observing and recording Transits, lately introduced in America; and on some other connected subjects."

The Americans of the United States, although late in the field of astronomical enterprise, have now taken up that science with their characteristic energy, and have already shewn their ability to instruct their former masters. The method of observing which it is the object of this lecture to explain, was apparently suggested at first by the obvious practicability of applying the Galvanic Telegraph (so extensively used in America) to the determination of differences of terrestrial longitude; and it was first used for the differences of longitudes of the cities Louisville, Cincinnati, and Pittsburg. It appears that this first application of the principle is entirely due to Dr. Locke of Cincinnati. It became, however, evident that the same method might be used conveniently for recording the observations made at one or at several instruments in the same observatory; and Professor Mitchell, also of Cincinnati, actually prepared an apparatus at the Observatory at Cincinnati, and with it made observations, specimens of which have been sent to individuals in this country. One of these specimens was exhibited by the Astronomer Royal to the meeting. Between the systems of Dr. Locke and Professor Mitchell there is one radical difference, namely, in the principles of giving the signal of observation; in the principles of recording the signal there is also a difference, but this

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difference is not essential, and there appears to be no reason why the same method of making the record should not be used in both systems. It will perhaps be most convenient to begin by describing the methods of making the record, which are, or may be, common to both systems.

The general principle of the methods, as regards the act of the observer, and its difference from the act in the ordinary observation of transits, is the following:—In ordinary observations the observer listens to the beat of a clock while he views the heavenly bodies passing across the wires; and he combines the two senses of hearing and sight (usually by noticing the place of the body at each beat of the clock) in such a manner as to be enabled to compute mentally the fraction of the second when the object passes each wire, and he then writes down the time in an observing-book. In these new methods the observer has no clock near him, or at least none to which he listens; he observes with his eye the appulse of the object to the wire, and at that instant he touches an index, or key, with his finger; and this touch makes, by means of a galvanic current, an impression upon some recording apparatus (perhaps at a great distance), by which the fact and the time of the observation are registered. He writes nothing, except perhaps the name of the object observed.

The method adopted by Dr. Locke was that of interrupted indented lines, produced by the pressure of a point or style (effected by a galvanic magnet whose current is interrupted occasionally) upon a fillet of paper, which is drawn by machinery with a nearly uniform speed under the style. With this apparatus it is evident that a signal almost instantaneous in duration can be given; either by supposing the ordinary state of the apparatus to be that of exerting a pressure on the style, and giving the signal by interrupting the galvanic current; or by supposing that in the ordinary state of the apparatus no pressure is exerted, and that the signal is given by completing the galvanic circuit, which animates the magnet and creates an instantaneous pressure. In the first of these forms the record will exhibit the appearance of long lines interrupted by very short intervals; in the second it will have the appearance of punctured dots, with wide spaces between them. Now, as no reliance whatever can be placed on the uniformity of speed of the machinery which draws the fillet, it is necessary to make such connexion of the apparatus with a trustworthy clock, that the seconds (or other uniform intervals) of the clock shall be recorded in the same manner upon the same fillet. If this be effected by the same galvanic communication and the same magnet, then, in the first case (or that in which the ordinary state is that of pressure on the style), the record will consist of an indented line, interrupted at short and sensibly equal intervals corresponding to the seconds marked by the clock, and interrupted also at other points corresponding to those instants at which the observer has, by a voluntary effort, interrupted the galvanic circuit in order to give a signal. This is the method adopted by Dr. Locke. In the second case (where in the ordinary state no pressure is exerted), there will be a series of punctured dots at sensibly equal intervals corresponding to the seconds of the clock, and, mingled with these, there will be the dots corresponding to the instants at which the observer has completed the galvanic circuit. This is the method adopted by Professor Mitchell.

In either of these methods there is no difficulty in producing such a variation, repetition, or omission, of the clock-signals, as will distinctly mark the beginnings of minutes, of every five minutes, &c.

Dr. Locke appears to have been induced to adopt the method of registering by interrupting the circuit (which in its ordinary state was complete), by the following consideration :—His object was to record upon one moving fillet of paper at Cincinnati the observations made at three stations (Louisville, Cincinnati, and Pittsburg,) and also the seconds of the clock. He remarked, then, that the interruption of the circuit for any one place would interrupt it for all; and therefore, at whatever place the signal of observation was made by interruption of circuit, the corresponding interruption would necessarily be made in the indented line on the fillet of paper. But he remarked also that the connexion of the parts of the circuit at one place would not effect the connexion for all; and he appears to have inferred that, if a single wire only were used extending along all the stations, it would be impossible to use it by the method of completing the circuit for signal, and that, in fact, a separate wire would be necessary for each separate station. This inference, as the Astronomer Royal shewed by diagrams, is incorrect. If the battery and the recording apparatus are near together, then it is only necessary to have a single trunk-wire passing by all the stations (including the clock as one); and to have a branch-wire passing through the recording apparatus to the battery, and a communication from the other end of the battery to the ground; and also to have a branch-wire through each station to the ground, interrupted in its ordinary state, but admitting of connexion at the will of the observer, or by the motion of the clock. Then, at whatever place the observer completes the connexion with the ground, the galvanic circuit through the recording apparatus is completed. Or, in the most unfavourable case (which is never likely to occur), of the battery at one extreme station, and the recording apparatus at the other extreme station, it is only necessary to have one trunk-wire proceeding from the battery through all the stations, and another trunk-wire parallel to the first proceeding from the recording apparatus through all the stations; then, at whatever station the connexion between these two trunk-wires (properly furnished with small branch-wires) is made by the observer, the circuit through the recording apparatus is completed.

The method of recording by the use of a fillet of paper, strictly speaking, is used only by Dr. Locke. The equivalent method used by Professor Mitchell is, to cause a circular disk to revolve with a smooth and nearly uniform motion (by means of a Fraunhofer's

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regulator), upon which disk the impressions of the style form a dotted circle; then, at the end of each revolution, a tooth upon the axis of the disk takes hold of a fixed rack and moves the travelling frame, which carries the centre of the disk, through a small space, so that the traces of the succeeding circle are prevented from mixing with those of the preceding circle. Professor Mitchell alludes to the practicability of using a cylinder which turns upon a screw axis, so that the traces will be made in a perpetual spiral; and there can be little doubt that this construction would be preferable to that of the circular disk. Among other reasons, the habitual estimation, or the measure, of the fractions of the seconds, would probably be more accurate where the length corresponding to a second is uniform, than where it varies from one circle to another, as it does on the circular disk.

The momentary interruption of the circuit in Dr. Locke's method, or the momentary completion in Professor Mitchell's method, for the register of observations, is made by touching a key nearly similar to that of a musical instrument. This key may be attached to the observing chair or to the astronomical instrument. Dr. Locke has not, however, fully described the mechanism by which he makes his clock interrupt the circuit. Professor Mitchell describes the action of his clock in the following manner:—A delicate fibre attached to the pendulum of the clock acts upon a "cruciform" lever [probably a rectangular or "bell-crank" lever], and thus, in every double swing of the pendulum, allows a metallic point to dip into a cup of quicksilver, and to complete the galvanic circuit. Thus, in Professor Mitchell's register the clock-dots are made at every two seconds. Professor Mitchell has found it convenient to use, for the seconds-record, a pen or style different from that which is used for the observation-record. He does not mention whether he uses for the seconds-record a battery different from that used for the observation-record; but this appears necessary to prevent the confusion which might arise in the register on making observations exactly at the second of time; for the completion of the battery-circuit by one wire would probably interfere with the efficiency of the circuit through the other wire.

The Astronomer Royal does not hesitate to express his preference of Professor Mitchell's form of register to Dr. Locke's.

The practicability of this method of recording observations being fully established, it then becomes an important question for the observing astronomer, whether this method is or is not more accurate than the usual method of observing by the combination of eye and ear. The question is, really, whether the connexion between the nerves of the eye and of the finger is or is not closer than that between the nerves of the eye and of the ear: it is purely a physiological question, which can be settled only by experience. Professor Mitchell has investigated it in the following manner. Extracting from the printed Greenwich Observations a number of transits of *α Coronæ*, and comparing their intervals with the intervals as established from observations of the pole-star, he has

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obtained a measure of what may be called Greenwich Irregularities. Using the same process for the observations recorded by the Galvanic Register, he has obtained a measure of Cincinnati Irregularities. The magnitude of the latter is only about one-fourth of that of the former. The Astronomer Royal suggested that a portion of this difference might be owing to the difference in the state of the two atmospheres, the atmosphere of England being perhaps comparatively unfavourable to accurate observation. The result of Professor Mitchell's comparison is, however, very encouraging as regards the probable success of the method.

One important advantage of this method would be the contraction of the time of observing a transit. Instead of using wires 12^s or 15^s apart, intervals of 2^s will be amply sufficient. Advantage may be taken of this, either for the observation of numerous objects, or for observation over numerous wires. One inconvenience of the method, however, is, the trouble of translating the graphical registers into numbers. Another inconvenience, of great weight, is the extent of recording surface that will be required, unless the recording machinery be very frequently disengaged, and its records (to a certain degree, not essentially injurious, but troublesome) be rendered discontinuous. In the Royal Observatory of Greenwich it is by no means uncommon to have trains of interrupted observations extending over twelve hours, or even a longer time, at once. An unbroken series of time-marks of 12 hours in Dr. Locke's method, allowing 1 inch to each second, would require 3600 feet of paper fillet; in Professor Mitchell's method, allowing $\frac{1}{3}$ inch for each second, and $\frac{1}{10}$ inch between successive lines of dots, it would require a sheet of 1440 square inches of paper.

The Astronomer Royal then stated that the possible advantages of this method appeared so great that he had begun to contemplate the practicability of adopting it in the Royal Observatory. One reason exists there which probably exists nowhere else, namely, the regularity of use of the Altitude and Azimuth Instrument by the method of transits, and the necessity of referring these transits (with the smallest possible uncertainty on personal equation) to the same clock to which the meridional transits are referred. In adopting Professor Mitchell's general method, he would propose to record the observations upon a cylinder, perhaps revolving upon a screw-axis. It is proper to remark, that this screw-axis may be so mounted upon friction-wheels that the friction would be quite imperceptible. The friction-wheels must not have their planes transverse to the axis, but in such a position that their edges follow the threads of the screw; and, supposing that there are two friction-wheels at each end, one of the four must be fixed in place, and the others must be mounted on frames which have a small hinge-motion in the direction perpendicular to the planes of the wheels. Or, instead of using the screw-motion, the frame which supports the axis of the cylinder may run upon a railway, along which it will be carried by rack-and-pinion mechanism, receiving its movement from the clock-work. The motion of the cylinder may be given by a toothed wheel

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on one end, which works in a stiff pinion, long enough to admit the toothed wheel to slide along it through a space equal to the length of the cylinder.

In using this cylindrical record, it is obvious that great convenience would be gained if the movement of the cylinder could be made so perfectly uniform that it could be adopted as the transit-clock. Then the second-registers could be made on it by the same clock which moves it (either by galvanic contact or mechanically), and their places would bear a constant relation to the lines parallel to the axis of the cylinder. The Astronomer Royal, therefore, urged strongly the importance of improvements of the centrifugal or conical-pendulum clock, as the only instrument yet made which is able to do heavy work with smooth motion, and with an accuracy at present so great as to make it probable that, with due modification, the greatest accuracy may be obtained. Setting aside the consideration of Fraunhofer's clock, as an instrument which, for purposes like these, is rude, the Astronomer Royal stated that, as he believed, the first efficient conical-pendulum clock was that made by Mr. Sheepshanks, in which the expansion of the balls to a certain angle produces suddenly a friction which, as soon as it amounts to an equivalent to the maintaining power, prevents further acceleration. Theoretically, the speed of this clock depends in a very small degree on the maintaining power. In order to remedy this small defect, the Astronomer Royal had introduced the use of water-power (by the modern form of Barker's mill or reaction engine) as the moving force, and had regulated the supply of water by Sieman's chronometric governor. The principle of this governor may be used in various forms; the following, perhaps, will serve to explain it most clearly. Suppose the last wheel of the moving-train to be a bevelled wheel whose plane is horizontal, carried by a vertical spindle; and suppose the spindle of the centrifugal balls to be above the moving-train spindle, in the same vertical line, but separate, and carrying a bevelled wheel similar to the other, but in the opposite position; and suppose the connexion between these two bevelled wheels to be made by an intermediate bevelled wheel, whose plane is vertical, and whose axis passes between the two; the train-spindle and the balls-spindle will evidently rotate in opposite directions. The axis of the intermediate wheel must not be fixed, but must be capable of turning in a horizontal plane, and it must be pulled by a weight (acting by a line over a pulley, or a right-angled lever), in the direction of turning the ball-spindle; it must also be connected with the water-valve in such a way that the same pull will tend to open the water-valve. It is evident now that, while the axis of the intermediate wheel is free to move, the force driving the bevelled wheel of the ball-spindle is rigorously uniform, and is equal to half the weight which pulls the axis of the intermediate wheel. If the moving power is suddenly increased, the immediate effect of this increase is, not to accelerate the ball-spindle, but to drive the intermediate wheel in such a manner that its axis lifts the pulling-weight, and partially closes the water-valve.

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An opposite motion takes place if the moving power is suddenly diminished. In this manner the water valve is maintained in that state which supplies the force that exactly produces a determinate moving power upon the ball-spindle.

In some localities it may be difficult to obtain the proper supply of water, and in some there may be danger of obstruction by frost. The Astronomer Royal had, therefore, endeavoured to effect the same object by the use of weights. By a remontoir-train the uniformity of rotation of the balls might undoubtedly be secured; but then the motion of the primary wheels of the train would be intermittent. The following plan, however, appears to the Astronomer Royal to be perfect. Let the arrangement of the three bevelled wheels and the pulling weight be exactly the same as that above described, but let the train-spindle carry a broad flat disk, whose plane is horizontal; upon this let a lever press by a definite projection from its lower side, and on the upper side of the lever let there be a sliding weight (as a ball running in a groove); let the spindle of the intermediate bevelled wheel command the place of this ball by a fork projecting downwards, loosely including it; and let the tendency of the pulling weight be to draw this ball towards or over the fulcrum of the lever, so as to diminish the pressure of its definite projection upon the flat disk. Then, if the moving force is suddenly increased, its immediate effect will be to drive the intermediate wheel in such a direction as to push the running ball further along the lever, and thus to increase the pressure of its projection upon the flat revolving disk, and to produce a friction which will absorb the excess of power.

There are still two practical defects which it is desirable to remove.

The first is, the amount of friction in the rotation of the balls, which, indeed, is so great, that in the clock-work used for equatoreal motion it consumes by far the greater part of the power. In the shape in which Sieman's regulator is usually applied to steam-engines, with one ball revolving by a rod whose support is a ball-and-socket joint, the friction is intolerably great. When balls are mounted on a vertical spindle, the friction, although much diminished, is still far too great. The Astronomer Royal had therefore directed his thoughts to the mounting of the conical pendulum, so as greatly to diminish the friction. In the summer of 1846 he chanced to see at the *Gewerbe Aufstellung* of Wiesbaden* a beautiful centrifugal-ball clock, intended for a drawing-room. The maker had acutely remarked that the circular motion might be resolved into two rectangular motions, and that each of these might be produced by the vibratory motion of a knife-edge. The pendulum,

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* The mechanical talent of inland Germany, having had little employment in the construction of powerful engines or manufacturing machinery, appears to have developed itself in the invention of clock-work. The Museum in the Schloss of Gotha contains a remarkable collection of clocks embodying every conceivable device. None, however, has appeared to the Astronomer Royal so remarkable for the accuracy of its mechanical conception as that which is described in the text.

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therefore, vibrated immediately by a knife-edge upon concave agates carried by a small frame, and this frame itself was furnished with knife-edges in the direction transversal to the former, which vibrated upon concave agates carried by the fixed frame of the clock. The pendulum thus moved with so much freedom that it was kept in conical vibration by a small maintaining power, acting ultimately by a light radial arm to maintain the rotation. The arc of expansion was determined (as in ordinary pendulums) merely by the resistance of the air.

This motion on knife-edges is liable to the same objections as the use of knife-edges for clock-pendulums. The Astronomer Royal therefore proposes to substitute for them a mounting by springs. The pendulum is immediately supported by two springs from a frame, and this frame is itself supported from the fixed parts of the clock-frame by two springs whose relative position is transversal to that of the former, and whose plane of vibration is transversal to that of the former; the form of the intermediate frame being such that, when the pendulum hangs in a vertical position, the upper ends of the four springs will be in one horizontal plane, and the lower ends will also be in one horizontal plane. A model of this mounting was exhibited. The motion is most satisfactory; the pendulum revolves many times before the diameter of its circle is diminished to one-half. In the complete clock-work the power of the train is to act on this by a radial arm.

The second defect, which will only be sensible when the mechanism has received these improvements (but of the distinct effect of which the Astronomer Royal has no doubt), is the want of compensation for the thermal expansion of the pendulum rod. Supposing the limiting arc of vibration determined by rotation within a ring, the contact of the rod with which produces the friction that prevents further acceleration, the Astronomer Royal proposes the following simple construction. The ring is to be of brass, and is to be carried in two or more points of its circumference by horizontal bars, each bar being supported at the extremity furthest from the ring by an iron pillar, and at some point between the iron pillar and the ring by a brass pillar; the pendulum rod and all other parts of the frame being of iron. The expansion of the brass ring, and its elevation by the effect of the different expansion of the two pillars carrying each horizontal bar, will both contribute (and may be made to do so to any assignable degree) to permit the greater angular expansion of the conical motion which is necessary for isochronism when the pendulum rod is lengthened by heat. [It is well known that the time of rotation of the conical pendulum depends only on the vertical depression of the ball below the horizontal plane passing through the centre of motion.]

It may, however, be thought preferable to employ a mercurial pendulum of the ordinary construction as regards compensation, revolving in a very small circle, whose diameter is perhaps equal to the usual arc of vibration of a common clock pendulum, and whose dimensions are limited only by the resistance of the air. The radial

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arm ought to act on a slender spike at the bottom of the mercury-cistern. The pulling-weight would be very light, but the efficiency of the regulation would not be diminished by that circumstance. No ring would be necessary, except as a safety-guard, to prevent the machinery from running wild on any accidental excursion of the pendulum beyond the end of the radial arm.

The Astronomer Royal then remarked that, considering the problem of smooth and accurate motion as being now much nearer to its solution than it had formerly been, it might be a question whether, supposing a sidereal clock made on these principles to be mounted at the Royal Observatory, it should be used in communicating motion to a solar clock. It might by some persons be thought advantageous, even now, that the drop of the signal-ball (at 1^h Greenwich mean solar time) should be effected by clock machinery; and it is quite within possibility that a time-signal may be sent from the Royal Observatory to different parts of the kingdom at certain mean solar hours every day, by a galvanic current regulated by clock machinery. Whether it would be advisable that this should be done by machinery proceeding originally from the sidereal mover, would be a question for consideration at the proper time; but, at all events, the Astronomer Royal desired to shew that the problem is practically possible to an astonishing degree of accuracy. Dr. Henderson, of Newferry near Birkenhead, had communicated to the Astronomer Royal, and had permitted him to make known to the Society, the following numbers for the teeth of wheels. If there be three spindles, Nos. 1, 2, and 3, No. 1 revolving in a mean solar day of 24 hours, or 86,400 solar seconds, and if No. 1 carries a wheel of 247 teeth working in a wheel of 331 teeth on No. 2, and if No. 2 also carries a wheel of 43 teeth working in a wheel of 32 teeth on No. 3, then No. 3 will revolve in $23^h\ 56^m\ 4^s{\cdot}09001$. Again, if there be four spindles, Nos. 1, 2, 3, and 4, No. 1 revolving in a mean solar day of 24 hours, and if No. 1 carries a wheel of 96 teeth working in a wheel of 79 teeth on No. 2, and if No. 2 also carries a wheel of 157 teeth working in a wheel of 133 teeth on No. 3, and if No. 3 also carries a wheel of 72 teeth working in a wheel of 103 teeth on No. 4, then No. 4 will revolve in $23^h\ 56^m\ 4^s{\cdot}09235$. The length of the sidereal day adopted in the *Nautical Almanac* is $23^h\ 56^m\ 4^s{\cdot}0906$. The approximations to it obtained above are very remarkable. By reversing the same train of wheels, accurate motion corresponding to sidereal time will be made to generate motion corresponding with the same degree of approximation to mean solar time.